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A novel contactless human-machine interface for laparoscopic telesurgery

Fabien Despinoy^{1,2,3}, Alonso Sanchez¹, Nabil Zemiti¹, Pierre Jannin^{2,3} and Philippe Poignet¹

1: LIRMM - CNRS, UMR 5506, University of Montpellier 2, Montpellier, F-34000, France

2: LTSI, University of Rennes 1, Rennes, F-35000, France

3: INSERM, UMR 1099, Rennes, F-35000, France

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Purpose

During the last three decades, the field of laparoscopic surgery has constantly been subject to technological advances looking to offer better healthcare in terms of safety, patient outcome, medical staff coordination and comfort [1]. Through the increasing availability of teleoperation systems for robot-assisted surgery, such as the *Da Vinci* (Intuitive Surgical Inc.), we have also seen an evolution of human-machine interfaces (HMIs) used to control these robots. Although their first function is to recover kinematic information from the surgeon's hands, they do have a direct impact on the overall performance of the system. This impact can be evaluated by means of multiple features which measure capacities of the HMI such as dexterity, bimanual exchanges, intuitiveness, comfort and precision, for instance.

In this paper, we present a continuation of a previous work [2] concerning a first experimental study to control a teleoperation system using a novel optical HMI, in the context of robot-assisted laparoscopic training.

Materials and Methods

The Raven-II system [3] (Applied Dexterity) is a bimanual robot composed of two 7 degrees of freedom (DoF) surgical manipulators dedicated to collaborative research in surgical robotics. This open platform was designed on a real-time controller using the Robot Operating System (ROS) framework. The robot control is ensured by a Cartesian position control based on a PID joint position control loop running at 1kHz. Connected through UDP, a master station allows kinematic exchanges with the robot controller.

To handle this robot, a new optical device named Leap Motion (Leap Motion Inc.) was plugged to the master station (Figure 1). Composed of 3 infrared (IR) lights and 2 monochromatic IR cameras, this device is able to track user's hands in a large field of view to control robot motions.

From the Leap Motion sensor information, a 7-DoF hand model was created using 3 particular tracking points which are the thumb, the index and the palm center of the hand. The position and orientation of the robot tooltips are controlled by the pose of the thumbs, whereas the grasping motions are handled by the angle between the thumb and the index of each hand.

Tremor filtering is applied on the hand models using an autoregressive moving-average (ARMA) low-pass filter, with an attenuation of 25dB at 2Hz [4]. Moreover, due to the optical nature of the device, special cares have been taken when tracking is lost and recovered afterwards so as to avoid bumps or unusual movements, ensuring safe and stable robot control.

Based on this model, every user can completely manipulate two robotized surgical instruments using only two fingers by instrument.

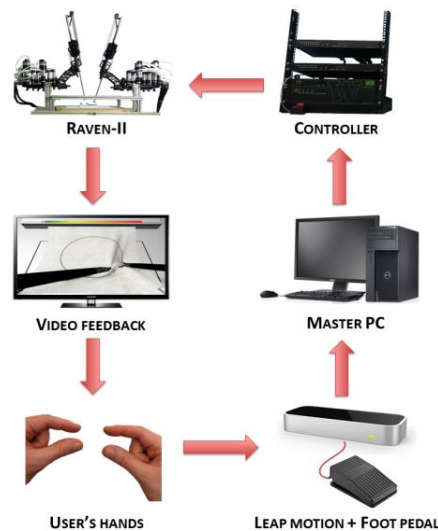


Fig.1. The teleoperation setup with the Leap Motion device, the master station, the Raven-II robot and a 3D camera for video feedback.

A preliminary performance evaluation of this new HMI was led on a population of ten researchers from the LIRMM lab. To carry out this experiment, we compared the Leap Motion device with the well-known Sigma 7 haptic interface (Force Dimension), used here as a reference for teleoperation control tasks.

The evaluation task consisted in the execution of a peg transfer scenario provided by the Fundamentals of Laparoscopic Surgery (FLS) exercises. The sequence was defined as follow: (a) Pick the first peg with the left tool and insert it in the leftmost target, (b) Pick the second peg with the right tool and insert it in the rightmost target, (c) Pick the last peg with the left hand, go to the center of the board and transfer it from the left to the right tool and then insert in the uppermost pin. From these experimentations, 30 trials were acquired (3 by candidates), including endoscopic videos and robot trajectories. Additionally, subjective information about the manipulation task were captured using an evaluation questionnaire at the end of the session.

Results

Recorded data were analyzed using JMP 11 software (SAS Institute Inc.) and Microsoft Excel 2010. On the one hand, we measured objective metrics such as completion time, percentage of success and clutching (number of activation/deactivation for repositioning) during the execution of the teleoperated task. From these first results, the leap Motion seems to perform as well as the Sigma 7 regarding the “duration” score (Figure 2a: +14s over a reference time of 101s) and “success” (Figure 2b: +12% over a reference score of 82%). However, considering the “clutching” score (Figure 2c), the Sigma 7 completely outperforms the Leap Motion. Note that this score has to be carefully considered because non-expected clutches appeared due to occlusions or tracking fails during the procedure which led to clutch in order to run again the robot.

On the other hand, we asked candidates to answer an evaluation questionnaire at the end of the session for a subjective evaluation. Here, five metrics were considered: reactivity, precision, intuitiveness, robustness and comfort (Figure 2d). The Leap Motion seemed to be well appreciated and easy to use relatively to the “reactivity”, “intuitiveness” and “comfort” subjective scores. However, the “robustness” and “precision” indexes indicate that some improvements need to be

considered. But generally, this new device obtained scores above the average rate which confirm that future large-scale experimentations should be considered for robot-assisted laparoscopic gestures, including other standard devices as well as a deeper analysis of the provided data (i.e. using video and kinematic data).

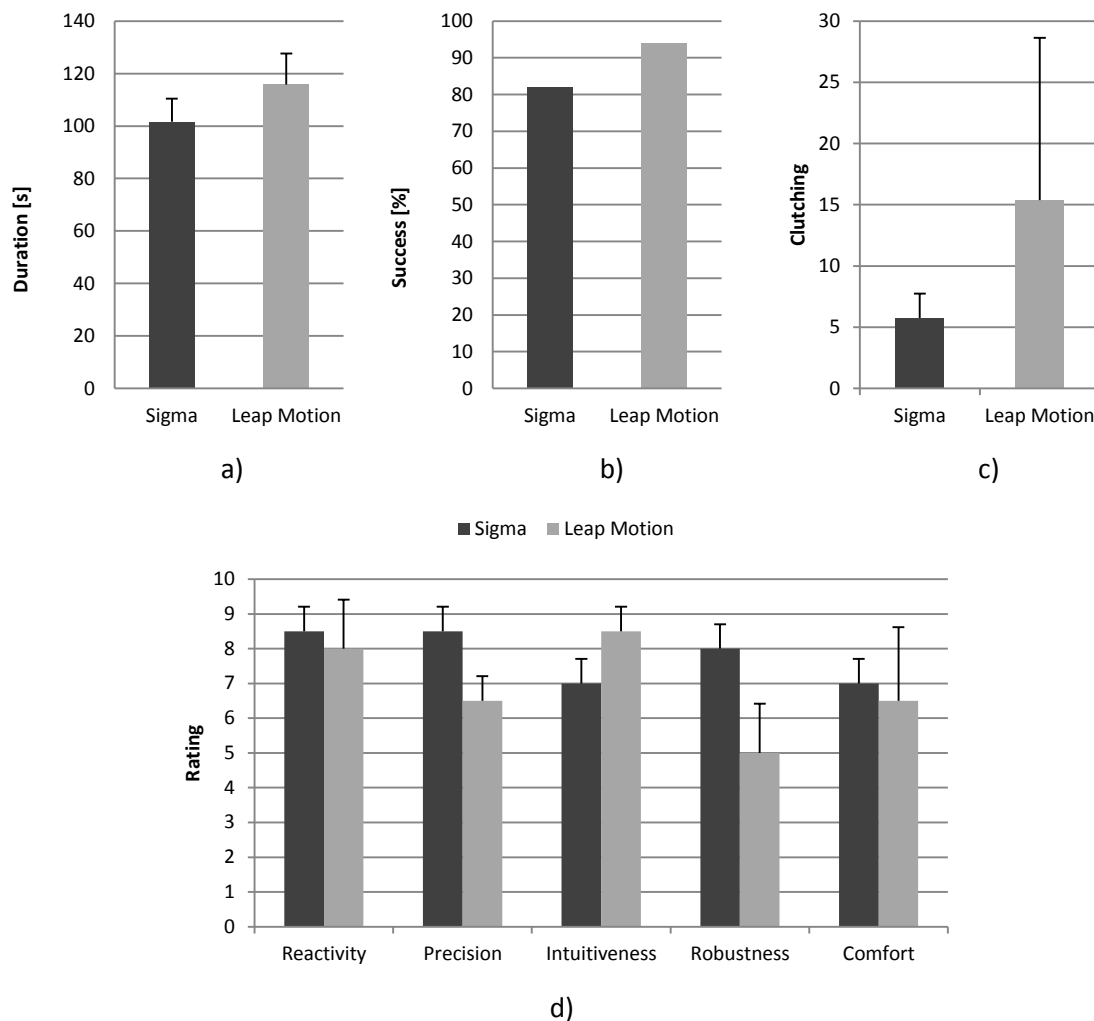


Fig.2. Comparison of the Leap Motion device by means of multiple metrics a) Completion time, b) Success of the execution, c) Number of clutching, d) Subjective metrics. Scores are represented by the mean value and the standard deviation from all candidates.

Discussion and conclusion

This work aims to evaluate a novel optical human-machine interface, namely the Leap Motion, for the execution of a laparoscopic training task. Connected to an open platform dedicated to research in robotics field, this HMI was evaluated and compared with the Sigma 7 interface by means of multiple metrics. From this preliminary evaluation, some draws can be concluded.

First of all, evaluation scores intend the leap Motion to be relevant alternative compared to standard mechanical HMIs due to small differences in terms of execution. Nevertheless real improvements need to be done with respect to user's opinions and technical issues, especially concerning occlusion and tracking fails, which could lead to better results for a larger evaluation campaign.

Moreover, some important features have to be also taken into account for the evaluation of HMI dedicated to teleoperated surgery. Two of them are the capacity to preserve asepsis during manipulation and the cost of the provided system.

In the first case, the Leap Motion device seems to be convenient for the integration in surgical teleoperation system due to its natural capacity to preserve hygiene with a contactless control. It simply avoids cleaning, waste of time to change gloves or necessary requirement to use plastic sheets and lead to an easier use in the operating room.

In the second case, a simple comparison between these two devices can be done: you can have access to more than 1,500 units of Leap Motion devices for the same price than two Sigma 7 (for bimanual teleoperation). Although the price of the last device is mainly justified by the embedded force feedback technology, a more convenient comparison should be done using Phantom Omni or similar “positioning” interfaces.

In any case, this preliminary assessment suggests that promising perspectives can be seen in the development of next-generation of human-machine interfaces in order to improve the efficiency and quality of computer-assisted surgeries.

Perspectives

Future works such as improvement of the occlusion management, integration of clinical experts and extension to other FLS tasks will be considered. Moreover, an advanced analysis on robot trajectories will be led for a quantitative evaluation of the HMI based on surgical gestures.

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Supplementary Material

A short video presenting material and experiments is available [here](#).

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